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NONDESTRUCTIVE EVALUATION (NDE) TECHNOLOGY INITIATIVE PROGRAM (NTIP)

Delivery Order 0032: MAUS Implementation for Corrosion/Crack Detection in Wing Structure – Phase III

Donald D. Palmer, Jr. and Nancy L. Wood

The Boeing Company
Phantom Works
P.O. Box 516
St. Louis, MO 63166-0516

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AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

NOTICE

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

/s/

JUAN G. CALZADA, Project Engineer
Nondestructive Evaluation Branch
Metals, Ceramics & NDE Division

/s/

JAMES C. MALAS, Chief
Nondestructive Evaluation Branch
Metals, Ceramics & NDE Division

/s/

GERALD J. PETRAK, Assistant Chief
Metals, Ceramics & NDE Division
Materials & Manufacturing Directorate

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14. ABSTRACT

This report summarizes the results of Phase III of the “MAUS Implementation for Corrosion/Crack Detection in Wing Structure” program. During Phase III, all system optimization activities, including hardware and software enhancements to improve ultrasonic pulse-echo data collection and data interpretation, were completed. Also completed was the B-52 upper wing spanwise splice inspection process development and validation. The automated second layer ultrasonic inspection procedure developed was designed to rapidly detect fatigue and stress corrosion cracking and will ultimately replace the manual low frequency eddy current inspection process currently used to support B-52 programmed depot maintenance. At the conclusion of this phase, one MAUS IV system located at Oklahoma City Air Logistics Center was upgraded with the “MAUS-Wing” enhancement package.

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PREFACE

This report constitutes the final deliverable under Phase III of the "MAUS Implementation for Corrosion/Crack Detection in Wing Structure", Delivery Order No. 01-S437-032-C1, Universal Technology Corporation (UTC) Prime Contract F33615-97-D-5271. This work was conducted under the technical direction of Capt. Matt Moye and Pamela Herzog (AFRL/MLS-OL) with management oversight provided by Dr. Tom Moran (AFRL/MLLP) and Dr. Robert Cochoy of UTC. Contributors to this report include the following:

Name	**Organization**	**Function**
Don Palmer	Boeing-St. Louis	Program Manager
Nancy Wood	Boeing-St. Louis	Automated Systems
Tom McGehee	Boeing-Wichita	B-52, KC-135 NDT
Bill VanSickle	Boeing-Wichita	B-52 Structures
Paul Rutherford	Boeing-Seattle	E-3 AWACS NDT

1.0 INTRODUCTION

As an aircraft ages, concerns regarding the presence of corrosion and fatigue cracks around wing skin fasteners arise. Visual inspection is currently the technique most often employed for wing skin fastener inspection. In some cases, the fasteners are removed and the holes inspected to look for cracks and/or corrosion. In other cases, the fasteners are left installed and manual ultrasonic or eddy current inspections are performed. For large area applications, these approaches are time consuming and costly. Also, visual/manual inspections have the potential for large margins of error.

A program entitled, "Structural Repair of Aging Aircraft" (SRAA) [1], a cooperative agreement between the Air Force and Boeing, worked to address reduction of Programmed Depot Maintenance (PDM) costs associated with damage detection and repair. One of the technologies the SRAA program pursued to address this need is the Mobile Automated Scanner (MAUS). It was assumed that, using multiple scanning modes, most of the manual inspections could be automated, thereby reducing inspection cycle times and improving the accuracy of the data. In addition, the SRAA program demonstrated the ability to detect cracks and corrosion in wing structure using an automated approach.

This program will focus on transition of MAUS ultrasonic and eddy current inspection modalities, incorporating current capabilities available with MAUS IV plus prototype system enhancements developed under the SRAA program (waveform capture and storage/rotational scanning). The overall objective of this program is to transition the enhanced MAUS system into B-52, KC-135 and E-3 aircraft depot overhaul processes and to subsequently reduce potential structural safety of flight risks. The specific objectives of the proposed implementation effort are to (1) significantly reduce cycle times associated with corrosion and crack detection in wing structure and (2) promote early detection of flaws in order to simplify repairs.

2.0 SYSTEM OPTIMIZATION

System Enhancements

During Phase II of this program [2], design parameters were defined for the pulse-echo signal conditioning circuitry, as shown in Figure 1. Three circuit boards are replaced in this design with slight modifications to a fourth board. All new board designs incorporated surface mount circuitry that allows greater circuit density on each board. Two boards that were previously connected via flat ribbon cable were directly coupled via connectors in a master/daughter board arrangement.

Circuit Board	Function	Design Goals
Four Channel Pulser/Receiver – New Board Design	Excites sensor and receives signal back from sensor	❑ Increase bandwidth to 30MHz ❑ Reduce circuit footprint to minimize noise ❑ Accommodate remote pulser/receiver on scanner hand ❑ Extend energy and damping ranges ❑ Accommodate spike and square wave pulsers ❑ Programmable low pass filters
Video and Peak Detection – New Board Design	Conditions sensor signal to prepare for time and peak amplitude detection	❑ Increase bandwidth to 30MHz ❑ Design to operator as daughter board on Data Conversion board ❑ Accommodate remote amplifiers and log amps ❑ Improve signal/noise ratio ❑ Add rectification options ❑ Improve front surface detection threshold
Data Conversion – New Board Design	Converts sensor signals to measure significant time and amplitude signals	❑ Reduce circuit footprint and accommodate detection daughter board ❑ Change from 8 bit to 16 bit data acquisition ❑ Improve event mark detection ❑ Improve depth linearity
Timing and Digitizer – Modified Board Design	Measures the time between event marks and A-scan display signals	❑ Change from 8 bit to 16 bit data acquisition ❑ Modify gating options – add discriminator gates

Figure 1: MAUS system optimization design parameters

During Phase III, the Video and Peak Detection and Pulse Echo Data Conversion boards were designed, fabricated and tested. The design of the Data Conversion board resulted in enough open board space to allow inclusion of the digitizer board functions. This resulted in reducing the MAUS board count by one board. In addition software drivers for the pulser/receiver, depth and amplitude readings and waveform data

acquisition were developed and incorporated. All system enhancements were completed at the end of Phase III.

Software Enhancements

Software enhancement focal areas included operator interpretation aids, automated thickness map/report, and enhancement to the rotoscan operator interface. During Phase III, all software enhancements were completed. A major portion of the software work centered on conversion of the MAUS ultrasonic data acquisition to 16-bit. This included modification of the ImagIn C-scan software to display 16-bit data and modification of the data system processor (DSP) software to support 16-bit data acquisition. The DSP software was also modified to support an ultrasonic angle beam approach envisioned for the B-52 spanwise splice inspection. As shown in Figure 2, four sensors are used to detect cracks in multiple orientations and verify sealant integrity. The original MAUS IV software presented these data as single ultrasonic parameters in the C-scan display. This modification displays the data as a separate parameter for each sensor and simplifies data interpretation

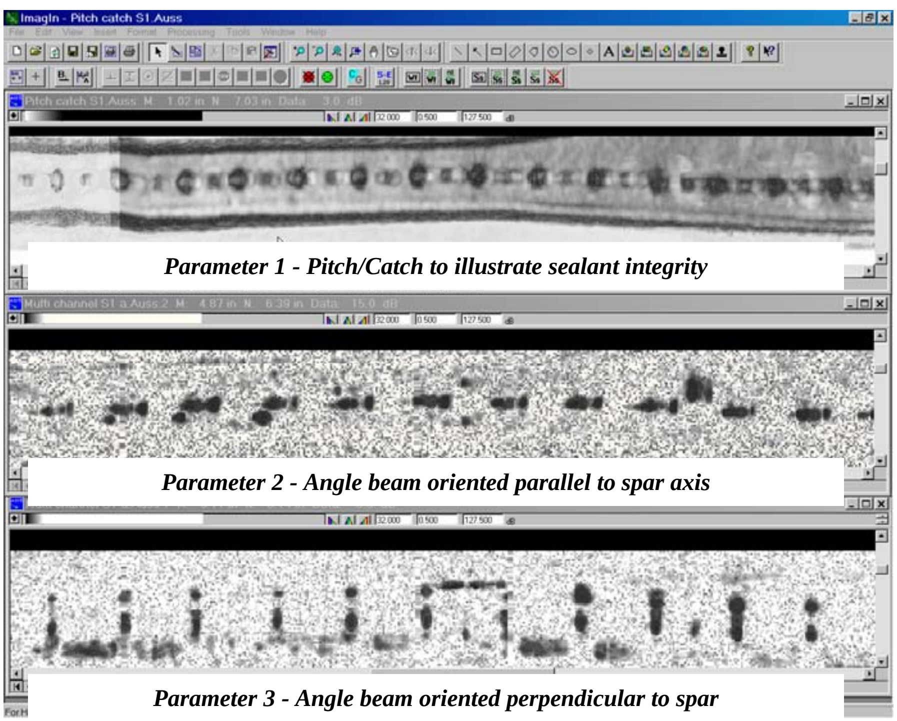


***Figure 2:Window illustrating multiple parameter data display*.**

The ImagIn software was also modified to add a centering evaluation tool to the B-scan display. This tool signals the operator when the rotational data set shows significant offset effects from the fastener signal response. In the example shown in Figure 3, the fastener marked in red has failed the evaluation and the fasteners marked in green have passed. A review of the B-scans associated with red and green fasteners show that the signal response from the fastener hole is non-linear relative to the fastener that failed the test.

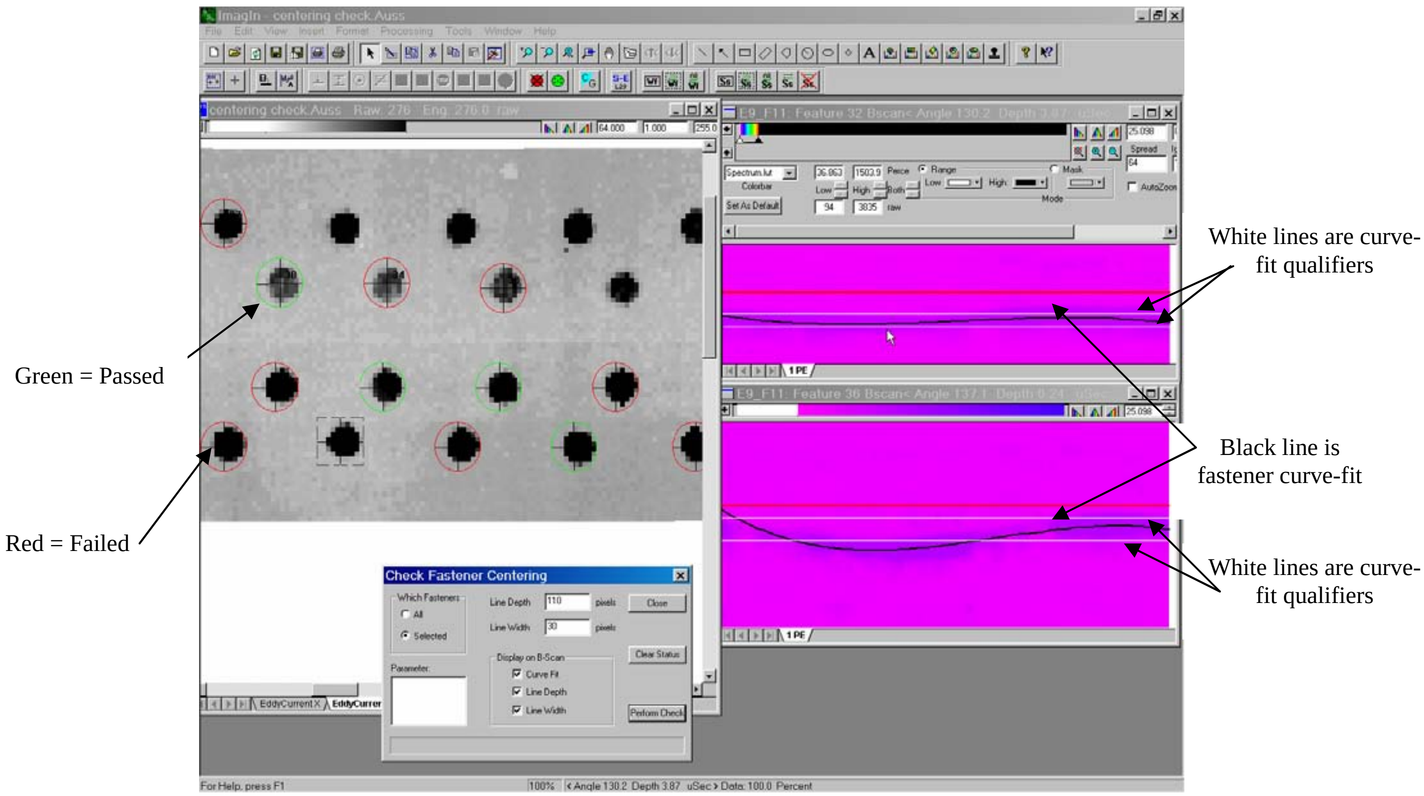


***Figure 3: Window illustrating data centering evaluation tool*.**

During evaluation of the annotation software, several areas for operator confusion were identified. As a result, a "software wizard" to prompt the operator through the annotation evaluation process was incorporated. In addition, the "SETUP" software was modified to allow separate gate settings for each sensor. This allows the operator to optimize the gates for the combined pulse-echo/shear wave sensor configuration envisioned for the B-52 spanwise splice inspection. Also, full waveform data acquisition software was incorporated and refined to include angle beam waveform collection. Angle

beam path and beam entry point variables were added to correct the A-scan and B-scan displays for angle beam characterization.

Mechanical Enhancements

A sensor fixture was designed and fabricated to position two sensors in a pitch-catch configuration during raster scanning. The solid geometry model is shown in Figure 4. The fixture includes a fine adjustment lead screw that changes the distance between the two sensors to optimize signal reflections in the pitch/catch configuration. The fixture fits into a standard MAUS sensor holder or linear slide, as shown in Figure 5. Flat surfaces around the fixture allow the sensor orientation to be clocked in 45-degree increments. The pitch/catch sensor fixture was subsequently modified to add one additional sensor perpendicular to the in-line pair, as shown in Figure 6.

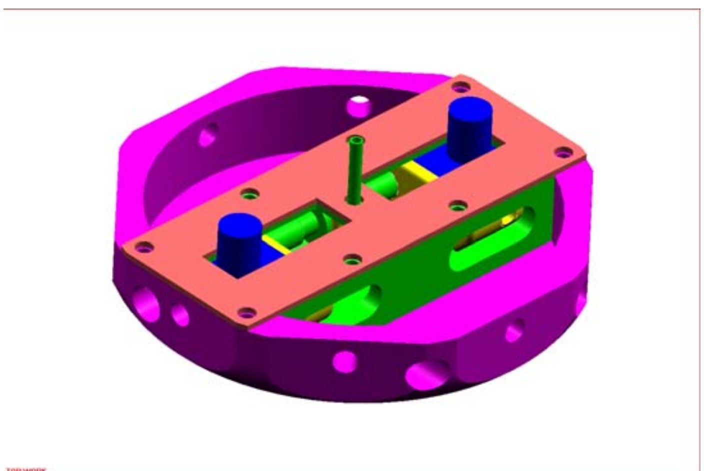
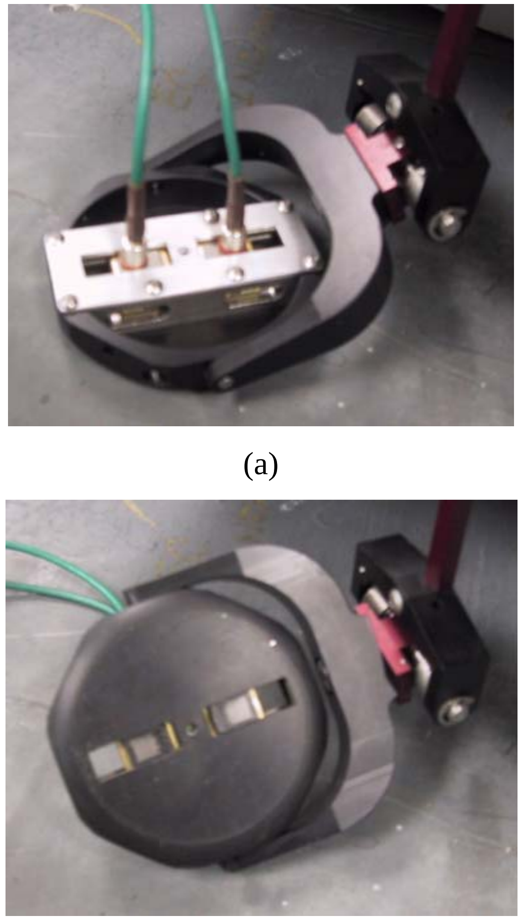


Figure 4: Solid model of pitch/catch sensor fixture



(a)

(b)

Figure 5: Pitch/catch sensor fixture (a) top view and (b) contacting surface view

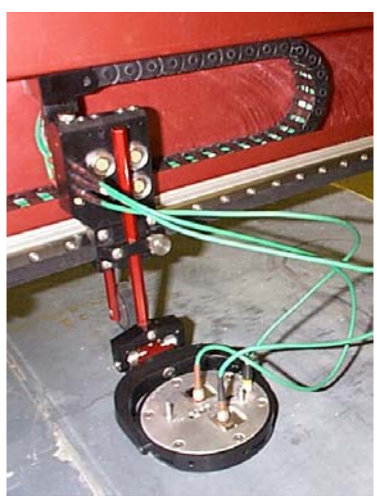


Figure 6: Final pitch/catch sensor fixture configuration with third sensor for raster scanning

From a rotational scanning standpoint, a fixture adapter was developed to attach the fixture to the rotational scanner. The rotational scanner linear slide design was modified slightly to allow for quick removal of the mechanism after an inspection is completed. Figure 7 illustrates the screw adjustment that removes the mechanism from the scanner. The final rotational scanner configuration is shown in Figure 8.

Figure 7: Removable linear slide

Figure 8: Final sensor configuration for rotational scanner

Sensor Definition

The Phase III sensor definition activity focused on identifying angle beam transducers to support a second layer ultrasonic inspection approach. The initial approach utilized four angle beam sensors, with two aligned to preferentially detect spanwise cracks and two aligned to detect chordwise cracks. Data are collected from each of the four sensors in pulse-echo mode and each pair in pitch-catch mode, resulting in six C-scan parameters. The pitch-catch data are collected to verify sealant integrity, assuring that the wave enters the second layer. The pulse-echo data are collected to detect the defect signals. Pulse-echo data from both sensors in a pair detects the defect from two directions. The data shown in Figure 9 were generated using this approach.

As was mentioned in the previous subsection, a third shear wave sensor was placed perpendicular to the pitch-catch transducer pair. The additional sensor was added to increase sensitivity to stress corrosion cracking. Stress corrosion cracks are typically more random than fatigue cracks relative to crack profile.

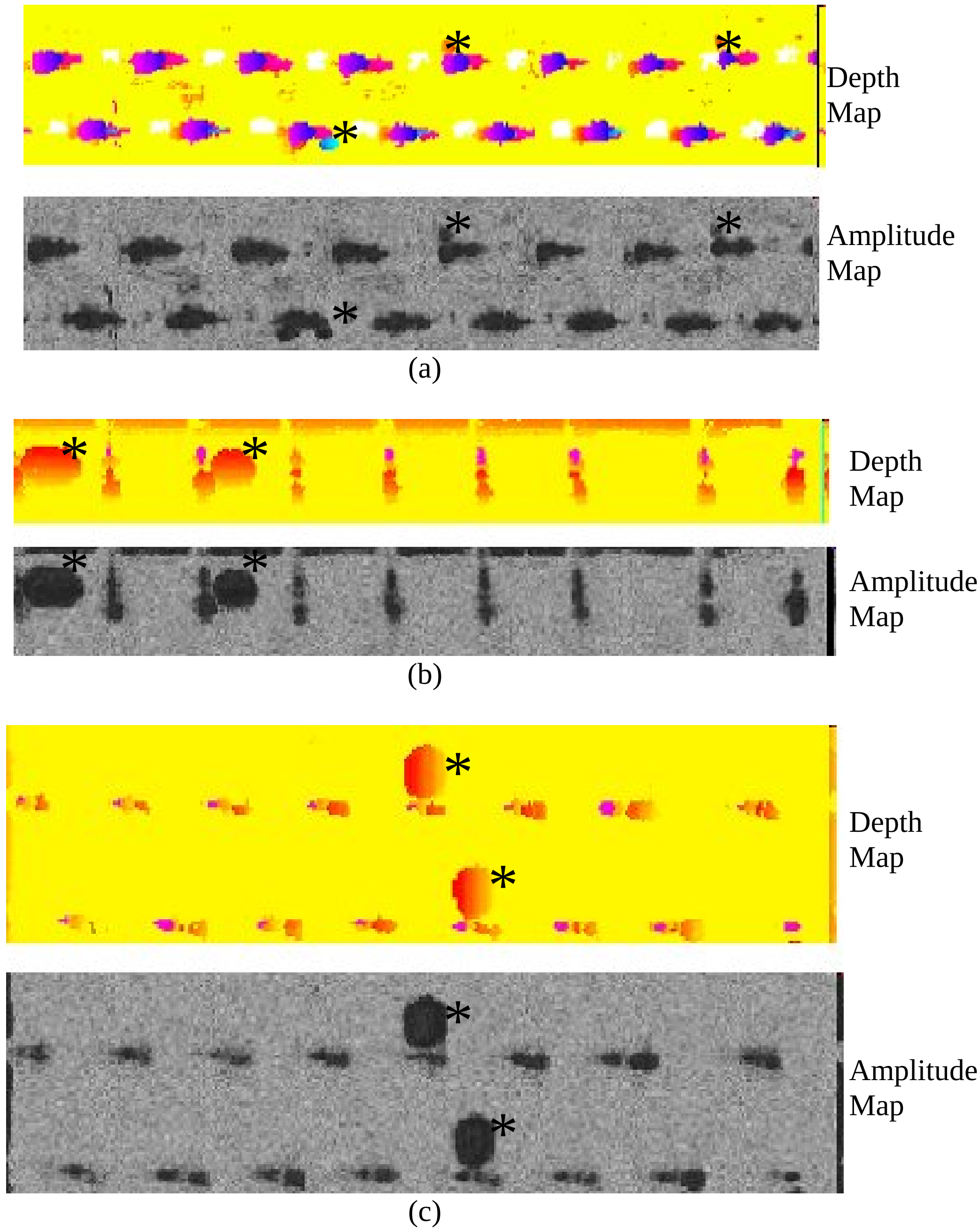


Figure 9: Multiple sensor pulse-echo data (16-bit) – (a) blind test standard, sensors oriented to detect chordwise cracks (second layer – 0.1 in); (b) initial test standard, sensors oriented to detect spanwise cracks (second layer – 0.5 in) and (c) initial test standard, sensors oriented to detect chordwise cracks (second layer – 0.5 in)
**** denotes crack location***

3.0 TECHNOLOGY IMPLEMENTATION

B-52 Program

The B-52 application defined, shown graphically in Figure 10, is the upper wing spanwise splice from BL55 to WS1025, splices 21, 24, 27 and 31. During Phase III, reference standard was finalized and the inspection process was developed and validated.

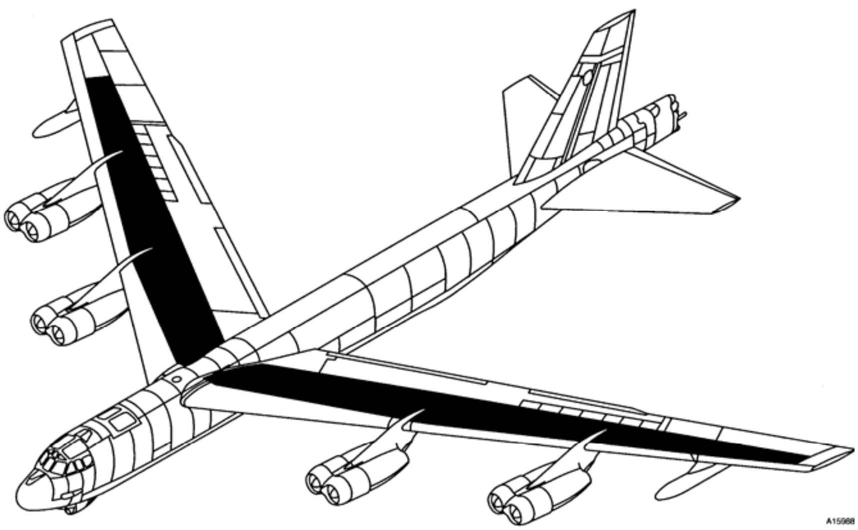


Figure 10: B-52 upper wing spanwise splice inspection area (shaded)

The reference standard for the B-52 spanwise splice inspection is shown in Figure 11. The standard contains EDM notches in both first and second layers ranging in size from 0.050 inches to 0.200 inches. These notches were machined in proximity to both steel fasteners and aluminum rivets to allow set-up relative to both scenarios. Skin thicknesses on the standard were a consistent 0.25 inches.

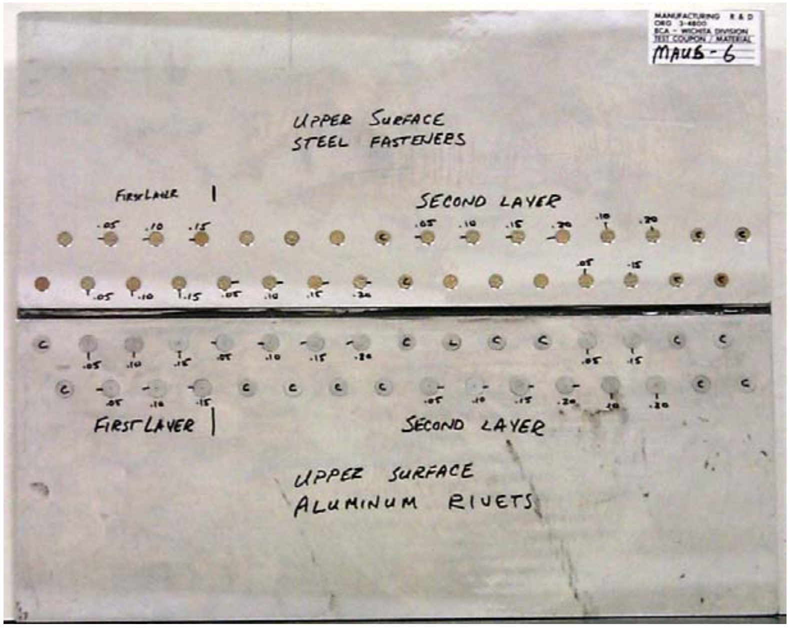


Figure 11: B-52 reference standard for MAUS inspections

Once the reference standard was finalized, a draft inspection procedure was completed based on the second layer ultrasonic approach discussed in Section 2. Data collected using the draft inspection procedure on the B-52 reference standard are shown in Figures 12 and 13 for spanwise and chordwise flaws, respectively. These scans demonstrate the ability to detect flaws in two orientations with one scan.

Prior to validation of the spanwise splice inspection procedure at Tinker AFB, a procedure review and initial validation were conducted at Boeing-Wichita. Four sections of B-52 wing structure representing approximately 90 feet of wing splices were scanned using the draft procedure developed for the optimized MAUS. Inspection of one section of spanwise splice is shown in Figure 14. Scan data were consistent from panel to panel. Based on feedback from B-52 Engineering personnel at Boeing-Wichita, minor modifications were incorporated into the draft procedure.

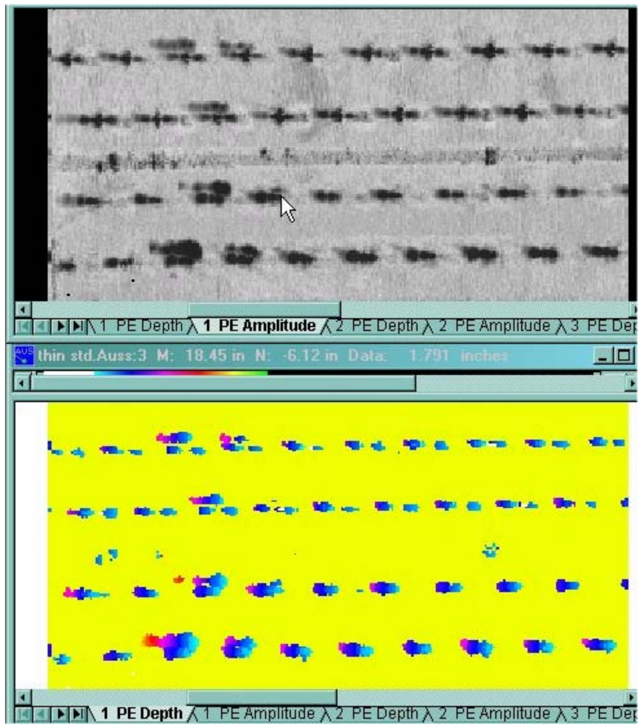


Figure 12: Pulse-echo C-scan data collected on B-52 reference standard showing chordwise flaw locations (sensor 1 output)

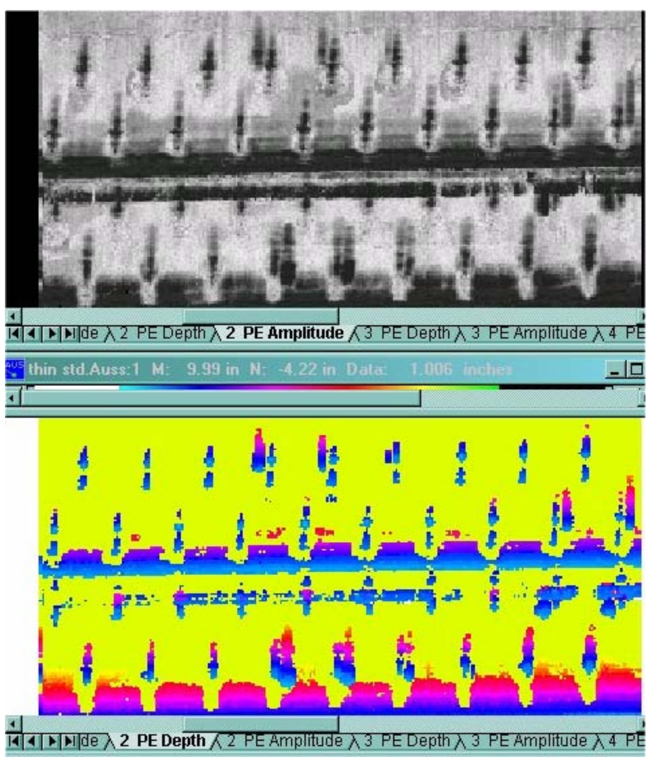


Figure 13: Pulse-echo C-scan data collected on B-52 reference standard showing spanwise flaw locations (sensor 2 output)

Figure 14: MAUS second layer ultrasonic procedure preliminary validation at Boeing-Wichita

A two-day validation/verification of the B-52 spanwise splice procedure took place on 13-14 May 2003. Oklahoma City ALC NDI personnel were present during the validation in order to become familiar with the process. Figure 15 shows the MAUS system on a B-52 wing during validation. Figure 16 shows representative C-scan images taken during the two days. This figure shows an example of the reflections encountered at the substructure intersection located at WS 312. Several images that were characteristic of geometry encountered in the part were recorded for inclusion into the interpretation section of the procedure.

Some minor changes to the test standard design were identified during the demonstration and validation. The defects within each section of the reference standard were redistributed to reduce the number of fasteners that are scanned to view all of the defects. In addition, the rivet spacing on the thicker specimens were increased to duplicate the spacing found on the aircraft. The close rivet spacing on the test standard masked some of the smaller defects in the validation/verification process.

Finally, the validation process generated some discussion on the final goals of the procedure. The initial goal of the inspection was to decrease the amount of time required to perform the inspection to less than 40 hours. Using the same detection resolution of the existing procedure, the new MAUS procedure will accommodate this reduction. However, since this procedure is more sensitive to smaller defects, there is a potential for increasing the inspection interval to two PDM cycles. This improved sensitivity comes at the expense of inspection speed such that the high-resolution inspection rate would be

similar to that associated with the current procedure. For example, at a 0.06-inch scan resolution, a single wing could be scanned in 4 hours. The 0.06-inch scan resolution corresponds to 0.20-inch flaw detection sensitivity. At a 0.04-inch scan resolution, it would take twice as long, or 8 hours to scan one wing. However, at 0.04 inches, the flaw detection sensitivity drops to 0.15 inches, which brings it into range for considering an extension relative to the PDM inspection interval.

Figure 15: MAUS attached to B-52 wing during process validation

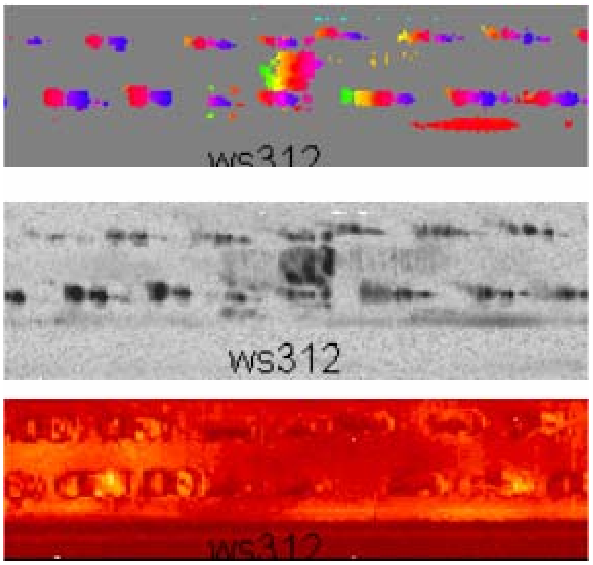


Figure 16: Images of the reflections encountered at WS312

As a result of the validation and the incorporation of the new pulse-echo circuit boards, the MAUS spanwise splice inspection procedure was modified. Several steps in the inspection process were modified to simplify set-up, including the removal of the stepped DAC function and the addition of full waveform acquisition relative to suspect areas. The final MAUS B-52 spanwise splice inspection procedure is included in Appendix A.

KC-135 Program

The application defined for the KC-135 during Phase II of this program [2] was the WS 360 upper wing splice, shown in Figure 17. This application was selected to replace the tedious manual eddy current inspection currently in place. The current inspection requires the use of high and low frequency eddy currents to detect cracking in the first and second layers. It also requires multiple set-ups with at least 10 reference standards. Given the emphasis on completion of the B-52 inspection process and the accelerated E-3 process development activities, little was accomplished relative to the KC-135 application. The bulk of the KC-135 process development will be addressed during Phase IV of this program.

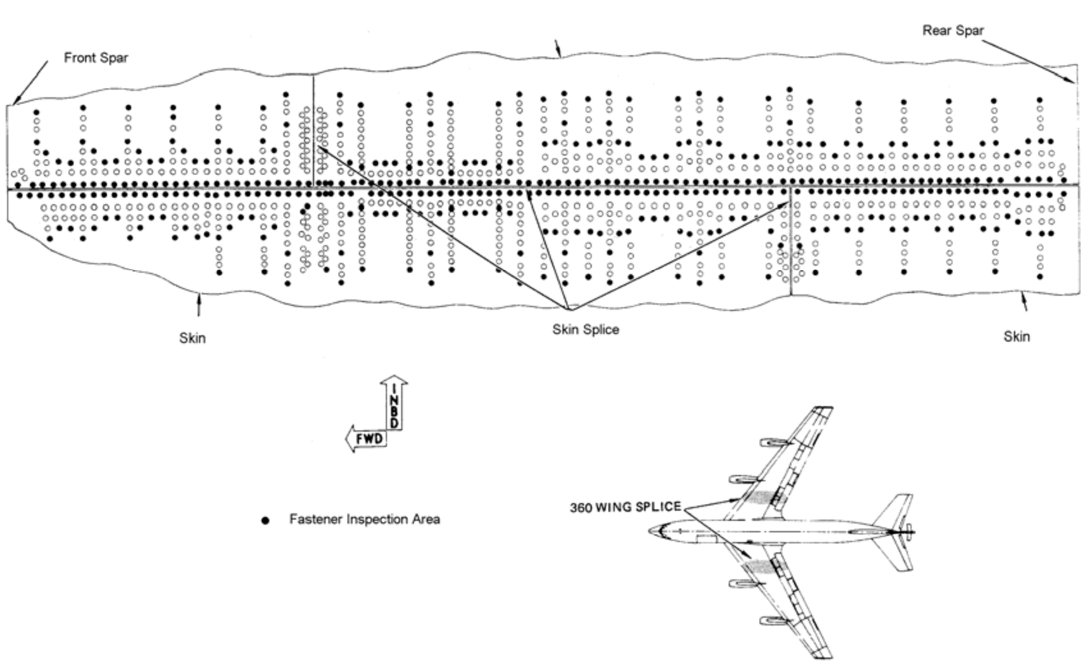


Figure 17: Sketch showing location of WS 360 splice on KC-135 wing.

E-3 Program

The application defined for E-3 implementation during Phase II of this program was a post-rework mapping of the upper wing skin [2]. The upper wing skin thickness mapping application entails the ultrasonic mapping of the skin thickness at steel lockbolt locations, as illustrated in Figure 18. Corrosion reworks on the upper wing skins have thinned the skin to the point where it is difficult to get an accurate prediction of the skin thickness. Design and fabrication of the upper wing skin thickness reference standard, shown in Figure 19, were completed. This standard was used to support procedure development activities during Phase III.

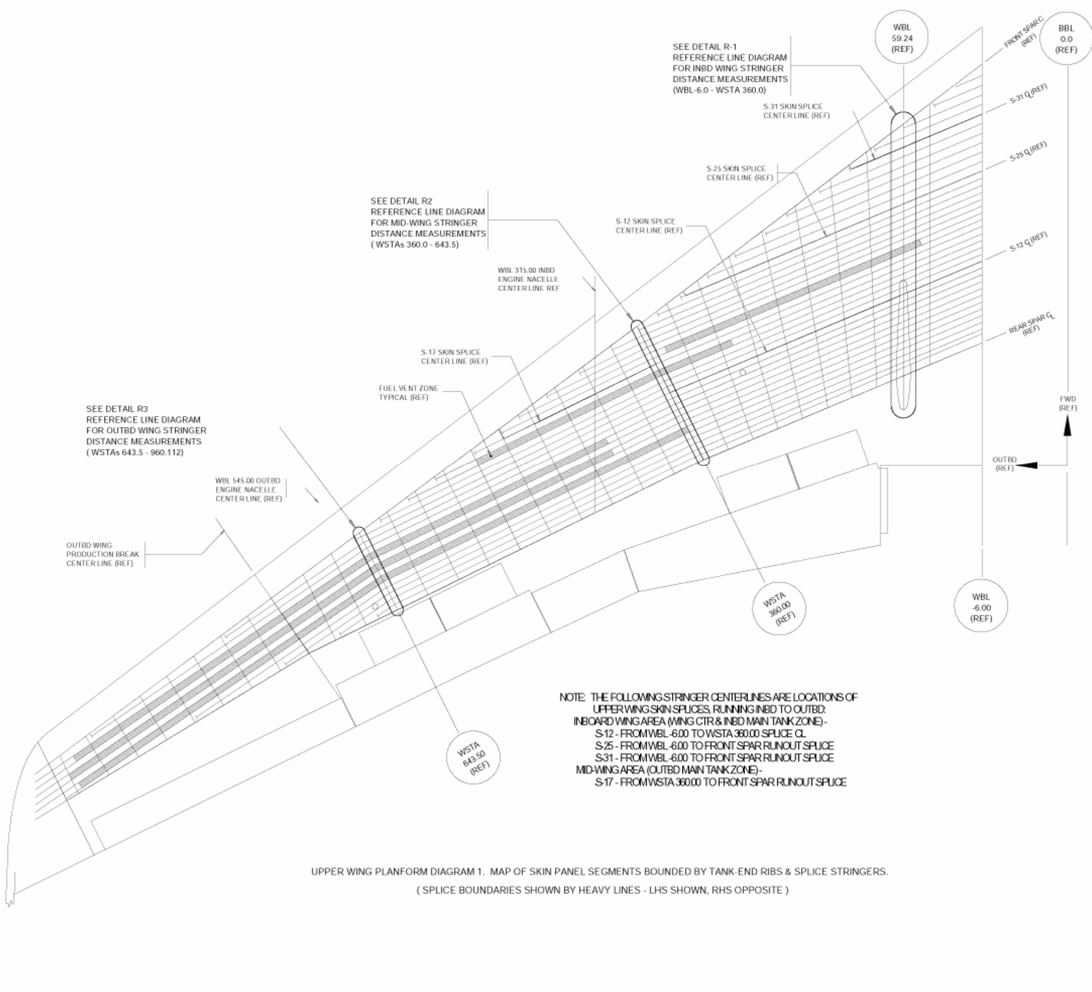
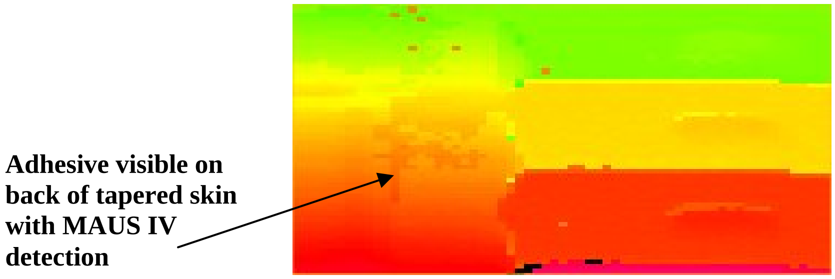


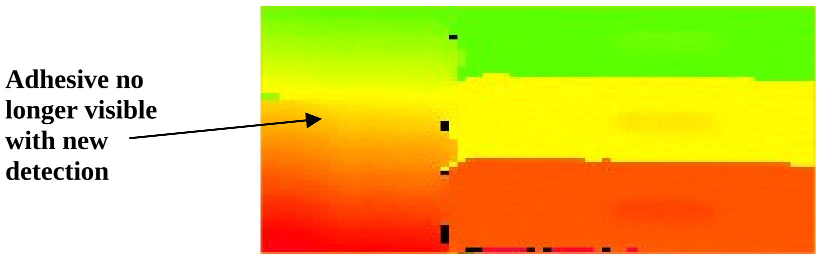
Figure 18: Steel fastener locations on the E-3 upper wing skin

Figure 19: Test standard for E-3 upper wing skin thickness gauging.

C-scan data were collected on the wing thickness standard using the new pulse-echo circuitry. The results indicated that the new event detection circuitry will help alleviate problems that were encountered using the MAUS IV for wing thickness evaluation. Figure 20(a) shows a C-scan that was collected on the test standard with rectification and gating settings similar to the MAUS IV setup. Note the area in the upper left corner of the standard where a rubber support foot is adhesively bonded to the back of the test standard. A slight thickness change is apparent in the ramp area that simulates the slight thickness increase encountered on the wing in areas with sealant on the back of the skin. Figure 20(b) is a C-scan collected on the same standard using a combination of rectification and gating options that is not influenced by the condition of the back surface.



(a)



(b)

Figure 20: C-scan comparison showing the effect of the new event detection circuitry: (a) MAUS IV set-up and (b) MAUS V rectification and gating

Normalization routines were incorporated into the ImagIn software to highlight small changes in thickness in tapered regions. The effects of these normalization routines are illustrated in Figure 21. The 0.005-inch notch milled into the back of the upper wing thickness standard is clearly resolved through the tapered region of the standard. This will ultimately be a key feature of the inspection process.

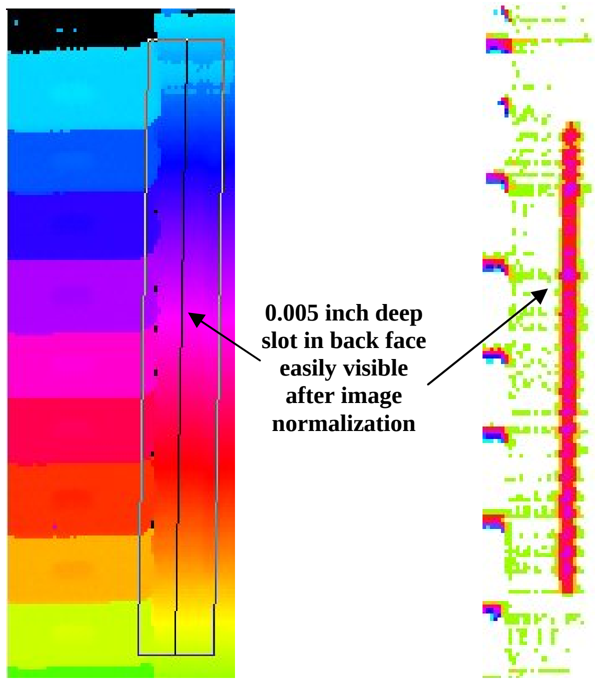


Figure 21: Normalization routine applied to tapered skin section of test standard

4.0 LOGISTICS SUPPORT

During Phase III, the activities relative to the Logistics Support task were limited to upgrading one of the MAUS IV systems located at Oklahoma City ALC with the new ultrasonic system and software enhancements, shown in Figure 22. Although the enhancements were incorporated into the system, OC-ALC requested that delivery be deferred until the eddy current enhancements being worked under a parallel program be incorporated as well, creating one MAUS V system. Training will be provided at the time of delivery.

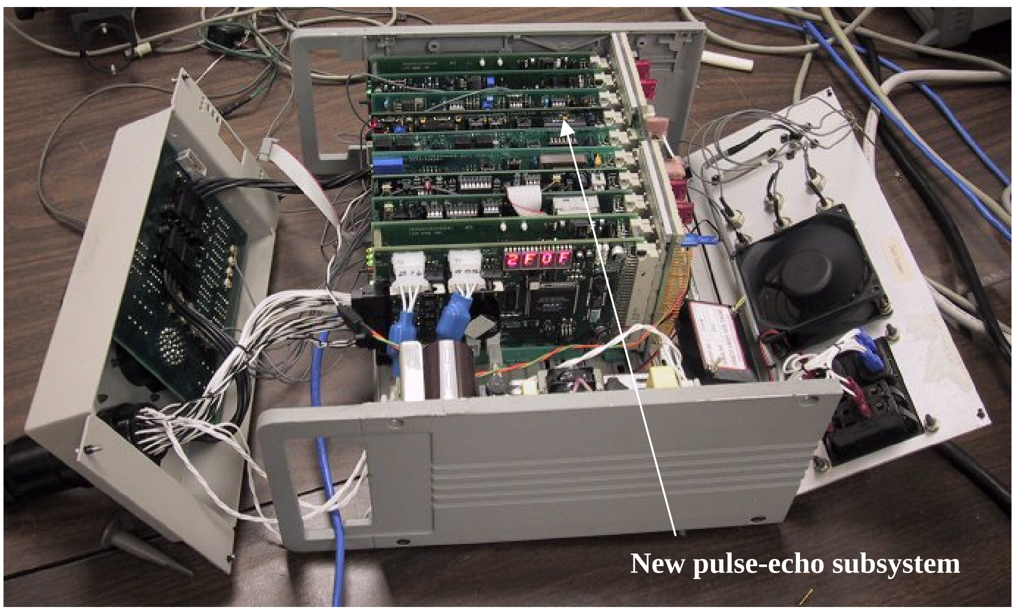


Figure 22: New pulse-echo subsystem incorporated into upgraded MAUS system

5.0 CONCLUSIONS/RECOMMENDATIONS

In summary, during Phase III, system optimization activities focusing on pulse-echo enhancements, data interpretation aids and sensor definition were completed. In addition, process development for inspection of the B-52 upper wing spanwise splice was completed, including process validation. Finally, the enhancement package developed under this program was incorporated into one of the MAUS IV systems located at the Oklahoma City Air Logistics Center. The status for each task relative to percent complete is shown below.

- System Optimization – 100%
- B-52 Implementation – 95%
- KC-135 Implementation – 30%
- E-3 Implementation – 60%
- Logistics Support - 33%

The plan for Phase IV will be to complete MAUS implementation for both the KC-135 WS360 splice and E-3 upper wing skin thickness mapping applications. This includes on-aircraft validation/verification. The logistics support activities will conclude with MAUS Data Storage and Retrieval (MDSR) upgrades, development of the Integrated Logistics Support (ILS) Plan and delivery of a new MAUS V system to the Air Force NDI Program Office at OC-ALC.

6.0 REFERENCES

1. D.D. Palmer, Jr., N.L. Wood, P.S. Rutherford, W.B. Shepherd, D.P. Roach, N.D. Schehl, “Structural Repair of Aging Aircraft”, Final Report # AFRL-ML-WP-TR-2001-4160, September 2001.

2. D.D. Palmer, Jr., N.L. Wood, “MAUS Implementation for Corrosion/Crack Detection in Wing Structure”, Phase II Interim Report, February 2002.

Appendix A:
B-52 Upper Wing Spanwise Splice Inspection - MAUS

1 Introduction

1.1 This procedure shall be used when performing ultrasonic angle beam inspection of the B-52 span-wise splice. It is designed to detect fatigue cracks and stress corrosion cracks in skins and spars. The inspection is performed on the upper surfaces of both wings at the locations shown in table A-1:

Table A-1. Inspection locations

Stringer	Wing station start	Wing station end	Excluded Areas
S18	WBL 55	WS 755	Overwing Pylon Attachment at WBL 410.
S21	WBL 55	WS 983	Overwing Pylon Attachment at WBL 410 and WBL 720.
S24	WBL 55	WS 1025	Overwing Pylon Attachment at WBL 410 and WBL 720.
S27	WBL 55	WS 1025	Overwing Pylon Attachment at WBL 410 and WBL 720.
S30	WBL 55	WS 1025	Overwing Pylon Attachment at WBL 410 and WBL 720.

1.2 This package defines the safety requirements, support equipment, materials, standardization, inspection, and interpretation procedures using the MAUS V inspection system.

2 Safety Requirements

2.1 Assure that safety requirements have been met before using electrical equipment on or near aircraft fuel cells, oxygen systems, and stores. When scanning fueled aircraft, conduct scans in a well-ventilated area with the MAUS V system at least three feet above ground level. Make sure the aircraft is electrically grounded to prevent electrostatic discharge and that the AC power is isolated from the aircraft.

2.2 Safety harnesses must be worn, when required, while performing this inspection.

2.3 A manual safety system must be used when the system is used on the underside of structure. Attach two safety lanyards to the carriage eye-bolt and to this manual safety system.

3 Support Equipment Required

3.1 The MAUS V inspection system shall be used when performing this inspection. This procedure requires three angle beam sensors. The sensors are aligned for scanning using the MAUS angle beam fixture. Table A-2 describes the required equipment.

Table A-2. Required equipment

Name	Part Number	Description	Manufacturer
MAUS V chassis and computer	MAUS V System or 257N144010	Multiple mode C-scan inspection system	Boeing
MAUS Variable Stroke scanner and track system	MAUS Variable Stroke Scanner and Flexible Track or 257N143002	18” bar scanner with flexible track assembly.	Boeing
Angle beam fixture – qty 2	MAUS-SS-Angle Beam or 257A143xxx	Sensor sleeve to hold two angle beam sensors	Boeing
45° angle beam sensors – qty 2	MMAB-0501-45AL	Micro-miniature angle beam sensors	Technisonic
36° angle beam sensors – qty 1	MMAB-0501-36AL	Micro-miniature angle beam sensors	Technisonic

3.2 Reference standards for this inspection are described in Figure A-1 below.

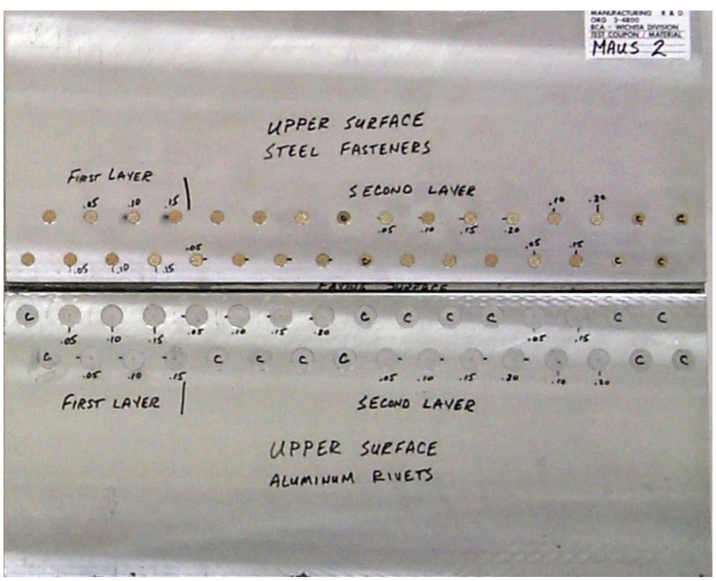


Figure A-1. Reference standard

3.3 Pressurized shop air and standard AC line power are required. Line power may range from 90V-240VAC. Air hoses and extension cords must be of sufficient length to reach from the wing root to the wing tip.

3.4 Water shall be used to couple the ultrasonic sensors to the part. A small amount of wetting agent such as water soluble couplant may be added to the water to aid in coupling.

4 Personnel Requirements

4.1 Personnel performing this nondestructive inspection shall have received specialized training applicable to this TO and shall be qualified and certified to perform ultrasonic inspections per any of the following:

4.1.1 Local NDI spec for UT inspection

4.2 In addition to the above, personnel must also be rated as a practitioner on the MAUS V inspection system. For the purposes of this document, a practitioner has been trained and certified to perform production NDT procedures with the MAUS V system.

4.3 A list of personnel approved to perform this test shall be maintained by the individual organizations via their existing training procedures.

5 Accessibility

5.1 Vortex generators located on the forward splice locations may create some access problems. It is possible to span over the vortex generators with the scanner as long as the support wheel and track are positioned to clear the generators.

6 Preparation for Inspection

6.1 Assure the inspection areas are clear of all foreign matter, sealant, grease, and oil. A thorough wash down of contaminated areas using soap and water is highly recommended. A mild abrasive pad may be used to facilitate cleaning.

6.2 Remove any excess sealant on the surface. Areas with excess sealant remaining must be inspected using the alternate eddy current procedure.

7 Equipment Setup

7.1 Assemble and power up the inspection system per the General MAUS V Procedure.

7.2 Insert the angle beam sensors in the sensor fixture as shown in Figure A-2. Note that the sensor connector is aligned on one end of the sensor. The sensor should be inserted so that the connector end is closest to the edge of the sensor fixture.

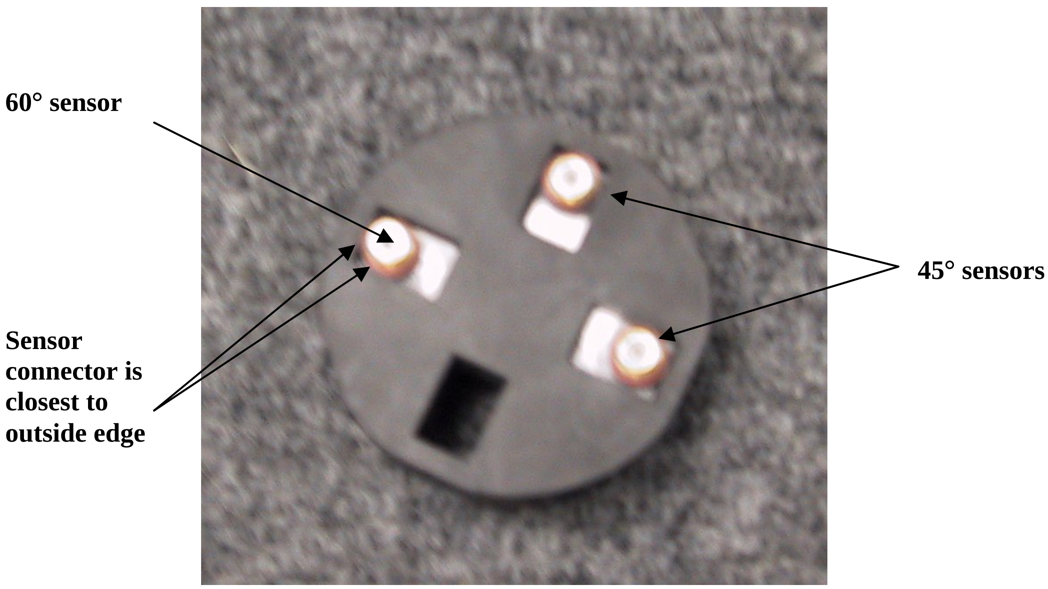


Figure A-2. Angle beam sensor configuration

7.3 Connect the green sensor cables to each sensor. The sensor numbering is shown in Figure A-3. Insert the other end of the green sensor cables into the sensor block on the scanner as shown.

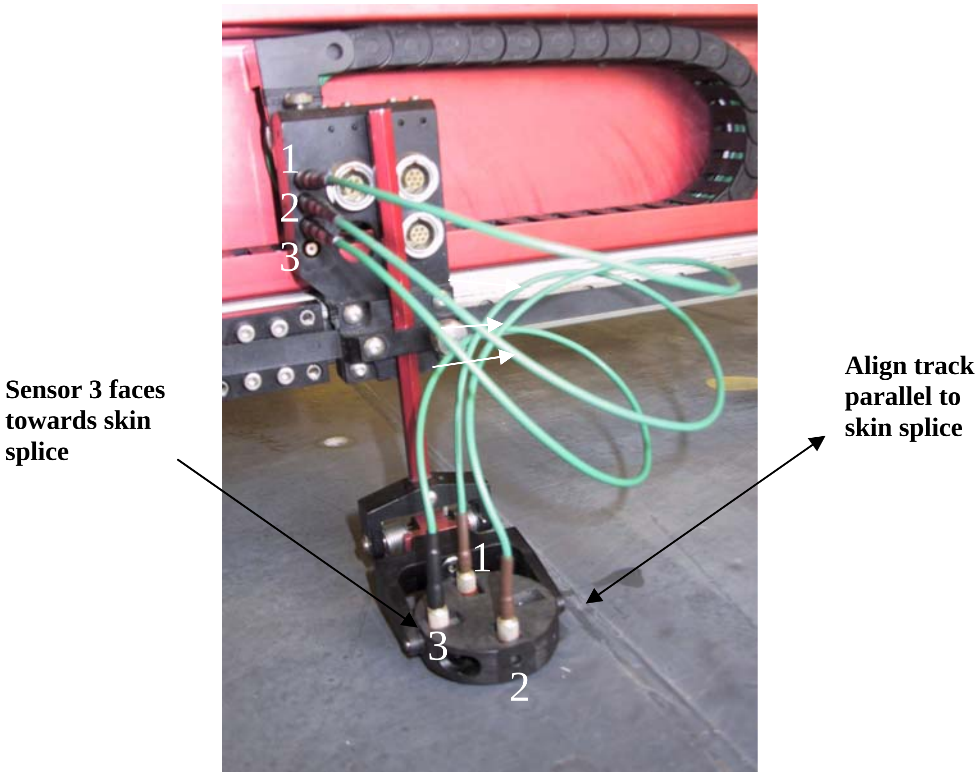


Figure A-3. Sensor nomenclature

7.4 Align a track section parallel to the skin splice, approximately six inches from the skin splice on the top skin. Place the track with two suction cups behind the starting location for the inspection. Use alignment guides, if necessary, to verify that the section is exactly parallel to the splice. Ensure that the track is firmly attached to the wing skin and that all of the suction cups are sealed on the surface.

7.5 Attach the sensor fixture to the variable stroke scanner with the yoke facing forward. Insert the sensor holder into the yoke on the sensor fixture as shown in Figure 3. Set the holder alignment so that sensors 1 and 2 are parallel to the track. Sensor 3 is perpendicular to the skin splice. Gently push the holder into the yoke until the yoke pins snap into the holder slots.

7.6 Engage the carriage lock and slide the variable stroke scanner/carriage assembly onto the track section. Position the carriage at the start of the track section. Release the carriage lock.

7.7 Adjust the variable stroke scanner angle so that the scanner is parallel to the wing skin surface. Adjust the guide wheel to support the scanner.

7.8 Place the test standard holder on the wing skin under the variable stroke scanner. Align the holder parallel to the track section Insert the correct test standard for the inspection configuration

7.9 Adjust the height of the sensor fixture to accommodate the test standard.

7.10 Place the sensor fixture on the test standard. Place a small amount of water between the sensor fixture and the test standard.

8 Standardization

8.1 Load the B-52 Spanwise Splice setup file. Check that the settings in the Setup menu are similar to the settings shown in Table A-3.

Table A-3: Preferred settings

Parameter	Setting	Comment
Control Tab		
Left Offset	x	This variable is set after the track and scanner have been placed on the wing surface
Stroke	2.5	This variable typically doesn't change if the Left Offset has been set properly
N Speed	50	This is the optimal speed for collecting data at 0.04" flaw resolution when using these pulse-echo setup parameters
M Speed	1	Setting the M speed variable to 1 puts the system in the single step mode – this is the fastest scanning mode
Overview Tab		
Flaw Resolution	0.04	This variable defines the data sample size
Mode	Uni-directional 1	This variable sets data collection as the sensors move outward from the track. Uni-directional 2 collects data as the sensors move toward the track.
Rotational Enable	Unchecked	This procedure does not use the rotational scanning mode. Do not check this box.
Offset Sensors	Checked	This procedure does account for offset positions between sensors. Check this box.
Sensor 1	Pulse-echo	Sensor 1 is set to Pulse-echo
Sensor 2	Pulse-echo	Sensor 2 is set to Pulse-echo
Offset	From Sensor 1	Offsets are used to align signals from sensors located at different positions relative to the scanner.
M Offset	0.15	Offset along the track axis

N Offset	0.00	Offset along the scan axis
Sensor 3	Pulse-echo	Sensor 3 is set to Pulse-echo
Offset	From Sensor 1	Offsets are used to align signals from sensors located at different positions relative to the scanner.
M Offset	0.00	Offset along the track axis
N Offset	0.00	Offset along the scan axis
Sensor 4	Pulse-echo	Sensor 4 is set to Pulse-echo
Offset	From Sensor 1	Offsets are used to align signals from sensors located at different positions relative to the scanner.
M Offset	0.00	Offset along the track axis
N Offset	0.00	Offset along the scan axis
PE Options Tab		
Pulsers	Angle Beam	The pulser mode is set to Angle Beam. This mode pulses sensors 1, 2, and 3. Sensor 4 carries the thru-transmission signal that is pulsed on sensor 1 and received on sensor 2.
Depth	1-2	Just one depth measurement from first to second event mark is measured
Sensor	5.0	5MHz sensors
Filter	Off	Filter set above sensor frequency to minimize filter effects
Collect Waveforms	Unchecked	Do not default to collect waveforms during C-scan data collection
Waveform Sample Rate	25	Set sample rate to 25MHz when specific waveform collection areas are defined
Data	Inches	Depth data is displayed in inches
Material Velocity	0.25	Speed of sound of the shear wave signal in Aluminum in inches
Amplitude units	Log	Display data in dB readings
Threshold 1	Depth Gate	Selects the Depth gate to start the depth measurement timing.
Threshold 1	40	Sets the threshold level for the first interface detection. Not used when Depth Gate is selected for Threshold 1.

Threshold 2	Threshold RF-	Sets the signal rectification for detection of a reflection to end the depth timing
Threshold 2	50	Sets the threshold level for detection.
Threshold Switching	0.1	Defines the time delay before depth detection switches from the front surface detector to the reflection detector
Depth Filtered RF	-Halfwave	Selects the signal rectification used for the A-scan display
Amplitude Filtered RF	-Halfwave	Selects the signal rectification used for the amplitude detection circuit
PE Gates Tab		
Depth Trigger	Main Bang	Start gate timing with the Main Bang
Start	0.5	Open the depth gate 0.5“ after the Main Bang
Width	2.0	Width time is long enough to include all expected reflections
Display	Gray	A-scan display for this gate is gray
Amplitude Trigger	First Interface	Start gate timing with the front surface marker
Start	0.2	No delay after front surface marker before the gate is opened
Width	1.5	Width time is long enough to include all expected reflections
Display	Light Blue	A-scan display for this gate is blue
Event Mark Width	0	Event mark width is set to minimum
Display	Black	A-scan display for this gate is blue
PE Sensors Tab		
Sensor 1, 2, and 3		Select sensor number to set the variables. Set the variables to similar settings for sensors 1, 2, and 3
Gate Selection	Common	This selection sets the same Depth and Amplitude gates for the three sensors
Energy	High	Energy is only set for all sensor when sensor 1 is set
Damping	Lowest	Damping settings are either Lowest or

		Medium. Set damping to Lowest.
Pre-Amp Gain	50	PreAmp settings add gain just when the signal is received. Use preamp to boost low-level signals without adding significant signal noise.
Depth Gain	20	Depth gain settings add more gain to the signal. Use gain for fine signal adjustments
Amp Gain	20	Amp gain settings add more gain to the signal. Use gain for fine signal adjustments
Sensor 4		
Gate Selection	Sensor	This selection sets different Depth and Amplitude gates for this sensor
Damping	Lowest	As described above
Pre-Amp	50	As described above
Depth Gain	20	As described above
Amp Gain	20	As described above
Depth Gate		Use similar settings as the Common gates
Trigger	Main Bang	As described above
Start	0.2	As described above
Width	4.0	As described above
Amp Gate		Set amplitude gate to include only the reflection from the second skin
Trigger	Main Bang	As described above
Start	1.0	As described above
Width	1.0	As described above
PE DAC Tab		
Trigger	First Interface	
Depth DAC		Time based gain added to depth signal
Preset	L4	A custom two step DAC boosts the signal from the second layer

Display	Blue	DAC shown as a dashed blue line
Depth DAC		Time based gain added to amp signal
Use Depth	Checked	Applies the same depth DAC to the amplitude signal
Display	Blue	

8.2 Place the sensor fixture on the test standard. Position the fixture so that Sensors 1 and 2 are located in the center of the splice between the fasteners as shown in Figure A-4.

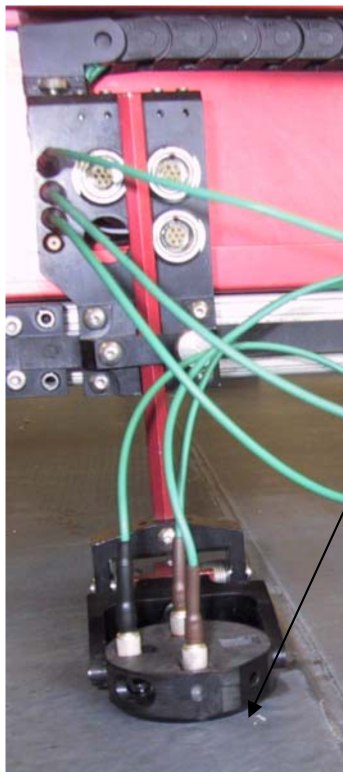


Figure A-4. Pitch/catch setup

8.3 Select the PE Sensors tab. Check that the Sensors variable is set to 4. This sensor displays a signal that is pulsed from Sensor 1 to Sensor 2. It is used to determine that sealant is intact in the structure and that sound is transferred into the second skin. At least two distinct peaks should appear in the blue Amplitude gate box, The first peak is a reflection from the back of the top skin, the additional peaks are reflections from the back skin and/or multiple reflections from the top skin.

8.4 Check that the default gates variable is not checked. When this variable is unchecked, the Amplitude Gate can be set differently for this sensor. Adjust the amplitude gate so that it starts just before the second signal peak and ends just after this peak. This should set the gate to detect the reflection from the back of the

second skin. Observe the amplitude reading at the top of the screen. Adjust the Amplitude Gain to set this reading to 4dB.

8.5 Position the sensor fixture so that sensor 1 is aligned with the 0.2” second layer setup notch in the test standard. Select the PE Sensors tab. Check that the Sensors variable is set to 1. A distinct peak should occur within the blue box as shown in Figure A-5.

8.6 Adjust the Depth Gain variable until this peak reflection is at least 75% of the screen height. Check that no black event marks appear in the gray box between the first wide event mark and the signal peak. Reduce the gain if extra event marks appear.

8.7 Observe the Amplitude reading at the top of the screen. Adjust the Amplitude Gain variable until this reading is approximately 3dB.

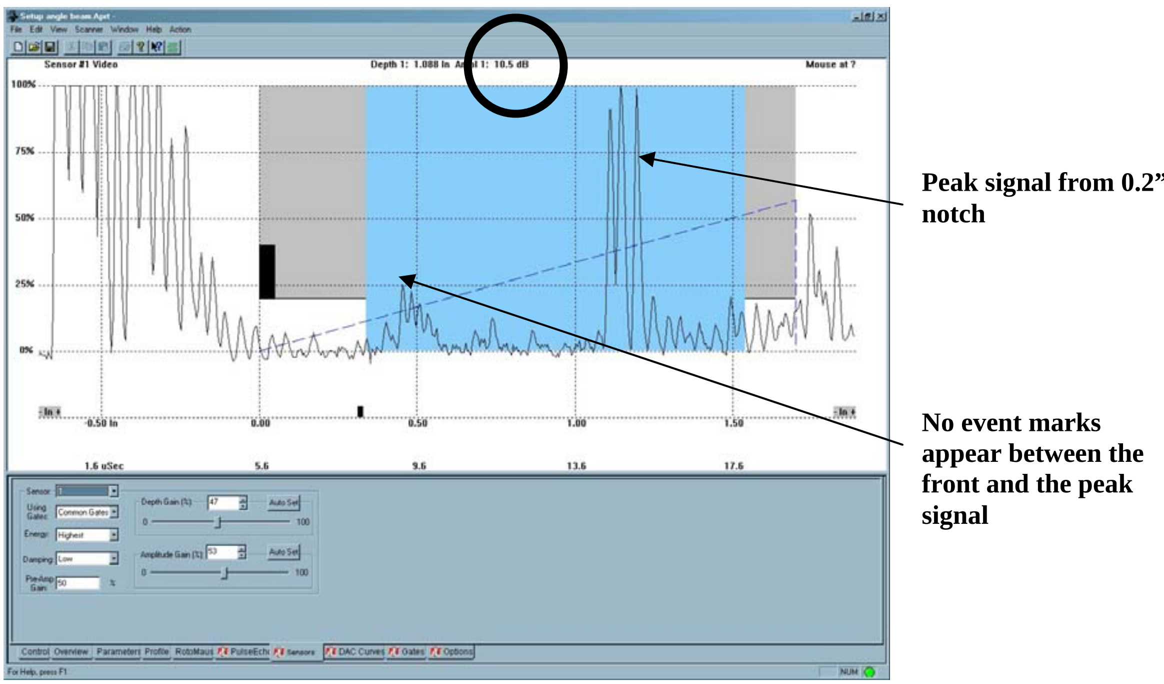


Figure A-5. Sensor gain setting for channels 1, 2 and 3

8.8 Repeat step 8.7 for sensors 2 and 3.

9 Inspection Sequence

9.1 See Table 1 for the areas to be inspected using the MAUS IV system. The entire area shown will be scanned using the shear wave setup. Any areas that demonstrate lack of sealant between the skin and spar will be rescanned using the original eddy current encircling probe procedure.

9.2 Separate scans shall be saved for each wing spar. Identify the aircraft tail number, the spar number, and the wing station start and stop locations for the scan.

9.3 Position the sensor fixture so that the sensor perpendicular to the wing splice is located over the splice. Press the Offset Set button in the Setup-Control menu. Check that the Stroke setting in this menu is 3”.

9.4 Press the Start Scan button in the Setup-Control menu. Enter the aircraft type, structure, tail number and wing location information in the variables at the bottom of the Start File menu. Select the Browse option to view the existing folders in the C:\Program Files\Boeing Company\Maus\Data directory. Locate the folder with the named with the aircraft tail number. If this folder does not exist, click on the New Folder icon in this Browse menu to create a new folder. Select the New Folder name and rename this folder using the aircraft tail number. Double click on the folder to select this folder for data storage. Enter a filename in the white box. The filename should be structured as follows:

B52 RHW Tail number Spar Wsstart Wsend

Click on the open button to return to the File Open menu. Click on OK to open the file for data collection.

9.5 The ImagIn window should open with four windows appearing on the screen. Check that the top left window displays the 1 PE Amplitude tab. The top right window should display the 2 PE Amplitude tab. The lower left window should display the 3 PE Amplitude tab. The lower right window should display the 4 PE Amplitude tab. If fewer than four windows appear, use the Window menu to create new windows and to Tile the windows for display. If the tabs are not selected correctly, position the cursor on a tab and click to select this tab for display.

9.6 Press the Scanner Forward tool to start the scanning. Press the Stop tool to stop scanning. The GoTo tool may be used to move a sensor to a particular position from the display window.

9.7 The scanner moves along the length of the inspection scan displaying the data from all three sensors in the ImagIn windows. Observe the data in the 4 PE Amplitude window to verify the presence of sealant. Mark the area as EC Alternate when sealant is not present. Return to these areas and perform the original eddy current encircling prove inspection procedure when the initial inspection is complete.

9.8 After the initial scan has been completed, rotate the sensor fixture by 45 degrees in the sensor yoke. Press the fast forward button to move the scanner forward by approximately 2 inches. Reposition the track at the start of the scan and run a second scan of the area with the sensors oriented 45 degrees from the original scan.

9.9 After the second scan has been completed, Press the Stop Scan tool to close and save the inspection data file.

10 Inspection Results

10.1 The shear wave data should appear as shown in Figure A-6. View the Amplitude tab for all three sensors for initial data evaluation. A fastener response appears as a straight line along the axis of the fastener. The angle of this line in the C-scan is dependent on the orientation of the fastener. It is important that the fastener response appear as long, thin lines.

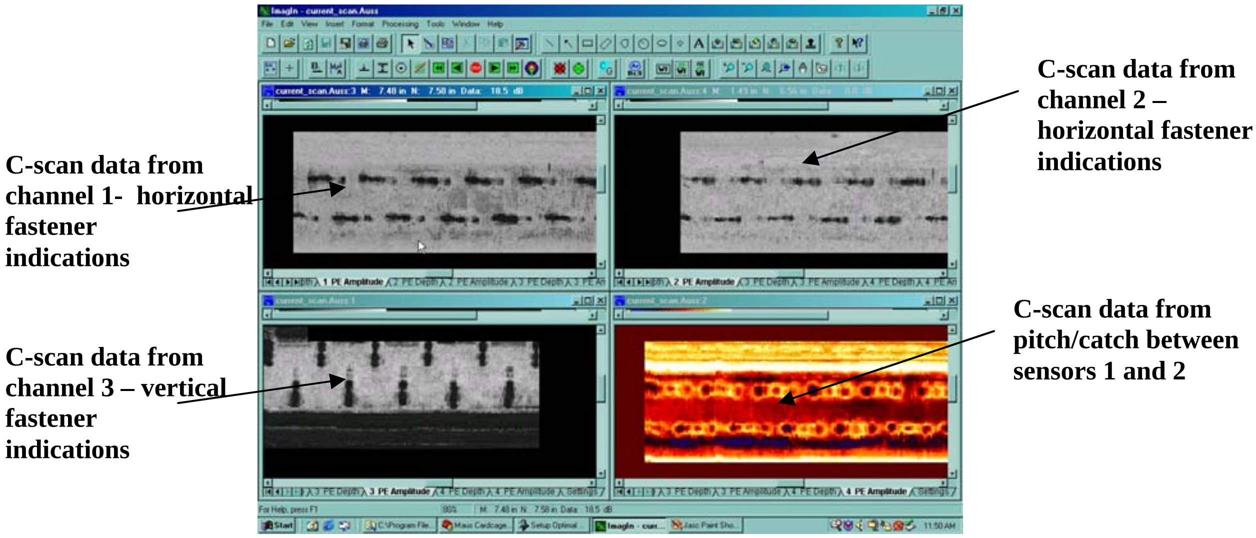


Figure A-6. Shear wave C-scan data

10.2 Crack indications appear as dark spots or lines on either side of the fastener line. The length of the indication indicates the length of the crack within 0.06” accuracy. The images shown in Figure A-7 illustrate small and long crack indications.

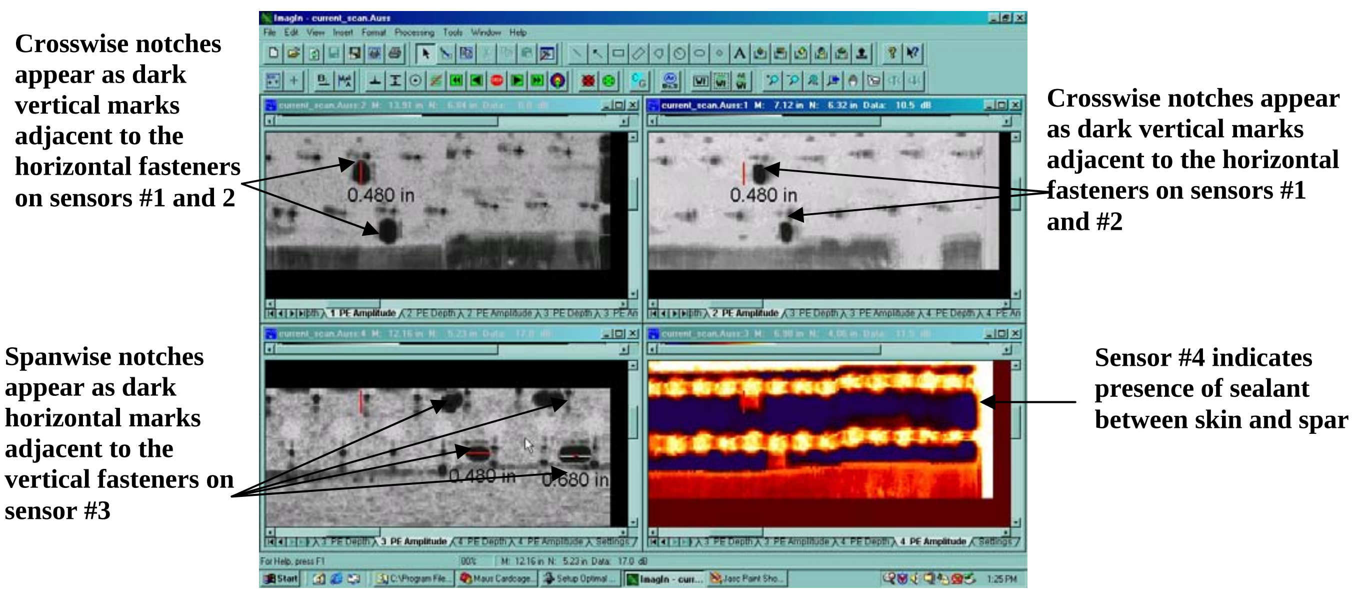


Figure A-7. Short and long crack indications in C-scan

10.3 Loss of couplant affects detection sensitivity. Monitor the Amplitude C-scan for Sensor 4 to verify couplant quality.

10.4 Evaluation criteria for defect indications are described below. Follow the criteria in this order. All criteria must be met to qualify the indication as a defect.

10.5 **Evaluation Criteria 1: The mark is clearly separated from the fastener line.** A defect may have one or several reflections that appear in a line just to the side of the fastener line. However, these marks will always appear as a distinctly separate edge. The sound wave reflections from the fastener and crack are shown in Figure A-8. A true crack indication appears slightly to the side of the fastener indication. Slight shifts in the width of the fastener indication represent variations in the fit-up of the fastener or the quality of the fastener hole.

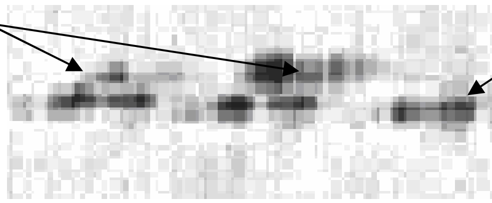


Figure A-8. Criteria 1: Clear separation of indication

10.6 **Evaluation Criteria 2: The depth reading changes across the mark.** Click on the Depth tab for the sensor that shows an indication. The depth reading for a crack indication changes as the sensor approaches the crack. A reflection from the faying surface shows a constant depth reading at all times. Figure A-9 shows the time-of-flight, or depth, difference. The reflections from a fixed reflector, such as a fastener or a crack, show depth changes from thick to thin as the sensor approaches the reflector. Reflections from a surface, such as the faying surface, do not show depth changes since the distance from the sensor does not change as the sensor moves over the surface.

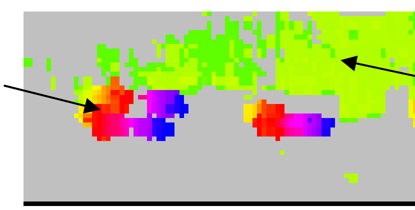


Figure A-9. Criteria 2: Depth reading changes within an indication

10.7 **Evaluation Criteria 3: The defect indication “lags” the fastener indication.** A crack indication appears slightly offset in time from the fastener reflection. The indication will “lag” the fastener reflection since sound waves will first reflect from the front edge of the fastener. Sound reflections from a crack emanating from a fastener hole travel slightly farther. Figure A-10 illustrates the time-of-flight differences in the angle beam C-scan between a fastener and a crack indication.

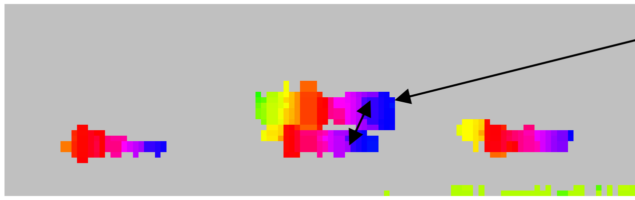


Figure A-10. Criteria 3: indication lags fastener

Time shifts can also occur from substructure effects such as rib intersections. However, these time shifts are typically much longer than the shift that would occur from a crack. Figure Y also illustrates the time shift due to a rib crossing. Table A-4 includes the locations of rib crossings for each stringer. Indications between the fastener rows may occur at these rib crossings. An example of these indications is shown below.

10.8 Special case: Shear ties are used at the skin/spar intersections described in Table 4. These shear ties may appear as a strong indication between the two fastener rows and should not be confused with crack indications. These responses, as shown in Figure A-11, fail Criteria 3 since the location of the defect is incorrectly aligned with the fastener indication.

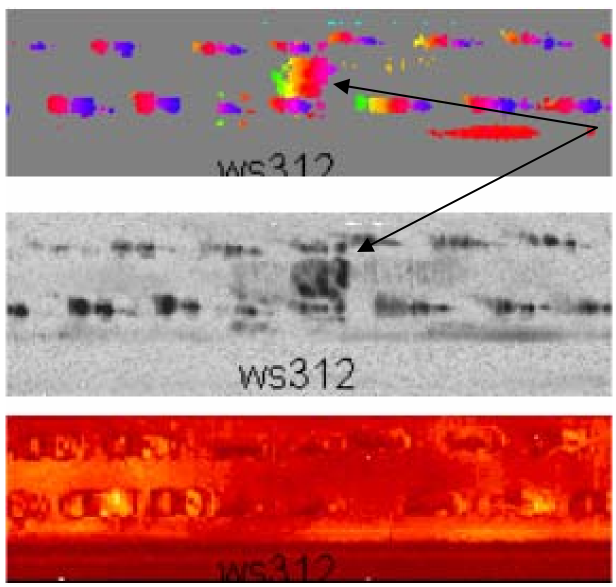


Figure A-11. Indications attributed to shear tie at WS312.

Table A-4: Shear tie locations

Stringer	Substructure effects at Wing Station
S18, S-21, S-24, S-27, S-31	WS222 (Shear Ties at Rib)
S18, S-21, S-24, S-27, S-31	WS312 (Shear Ties at Rib)

10.9 A series of rubber stamps are available to aid data interpretation. Click on the rubber stamp icon to view the rubber stamp box. Select the Fasteners folder in the

rubber stamp box. Select forward for Sensor 1, reverse for Sensor 2, and down for sensor 3. Click on a fastener in the image to place the annotation on the fastener. Click on the Select arrow, then click/hold and drag the annotation to place the large rectangle directly over the fastener response. Crack indications will appear within the two small boxes in the annotation. Indications that appear outside of the small boxes are likely to be non-crack indications.

11 Defect Identification and Sizing

11.1 A defect indication that meets all of the evaluation criteria should be physically marked on the wing skin. Full waveform data should be collected from the fastener with the defect indication. Select the Waveform outline tool from the ImagIn toolbar. One inch above and two inches behind the defect indication on the C-scan. Press and hold the mouse button. Drag the cursor to create an outline around the defect indication. Release the mouse button to complete the outline. Press the Collect Waveform tool in the ImagIn toolbar. The scanner will rescan the area outlined in the C-scan and collect full waveform data for additional data evaluation.

11.2 Use the Line tool to size the indications as shown in Figure A-12. Select the Line annotation tool. Place the cursor at one end of the indication and click the left mouse button. Place the cursor on the other end of the indication and click the left mouse button. Move the cursor to the side of the line and click the left mouse button to place the length annotation on the image.

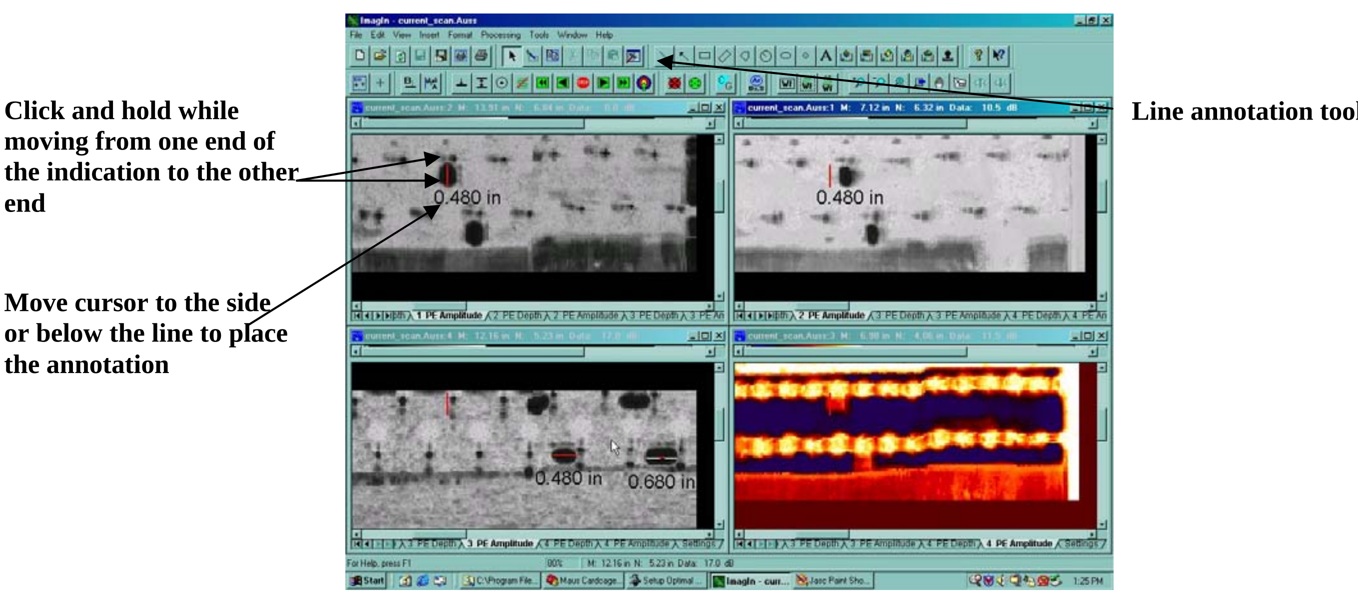


Figure A-12. Defect measurement using the line annotation tool.

12 Acceptance Limits

12.1 Annotate all crack indications on the data image. Report any indications that appear within the two small rectangles of the Fastener annotation. All crack indications shall be confirmed using a bolt-hole eddy current inspection method.

13 Documentation of Results

13.1 Mark all fastener indications on the aircraft as the data is collected. Report all fastener indications.

14 Post Inspection Procedure

14.1 Secure and remove all test equipment from the area.

14.2 Insert a CD ROM into the CD Writer. Follow the instructions to create a Data CD. Select all inspection files for data transfer. Create a CD name using the file naming protocol described in section 9.4.

14.3 Transfer all inspection files to the MDSR (MAUS Data Storage/Retrieval) system.

LIST OF ACRONYMS

ACRONYM	**DESCRIPTION**
ALC	Air Logistics Center
DAC	Distance Amplitude Correction
DSP	Data system processor
EC	Eddy current testing
EDM	Electric discharge machining
ILS	Integrated Logistics Support
MAUS	Mobile Automated Scanner
MDSR	MAUS Data Storage and Retrieval
NDI	Nondestructive inspection
PDM	Programmed depot maintenance
SRAA	Structural Repair of Aging Aircraft
UT	Ultrasonic Testing